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Cost Effective Subsea Rock Removal Tool for Deepwater Applications

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ABSTRACT

A Cost-Effective Subsea Rock Removal Tool for Deepwater application was developed for removal of subsea rock outcrops at 300-500m water depth in the Norwegian Fensfjorden. Subsea rock outcrops were restricting pull-in of the 36" oil export line from the Johan Sverdrup field to Mongstad through a 48" borehole, and a simple low-cost method for subsea rock removal without the use of explosives was developed for this purpose. The developed method reduces the need for traditional seabed intervention and hereby reduces the number of days involving Marine Installation vessels. This contribute to a positive impact on overall cost, HSE and Carbon Emission. The simplification is combining already existing subsea tools into one new tool for subsea solid rock removal. The application was successfully used in Fensfjorden for three different tasks October/November 2017 and March 2018. The method adds a new tool to seabed intervention, making route selection and pipeline installation in near shore areas with challenging seabed more flexible.

KEY WORDS: ROV drilling; WDTH (Water powered Down-The-Hole); deep water; subsea; pipe lay route; hydraulic rock splitting.

INTRODUCTION

Deep water rock formations have traditionally been avoided during pipeline route selection instead of being modified to allow for safe pipeline installation. This is mainly due to lack of proven tools for deep-water rock removal and/or due to high costs for the operation. For the deep-water challenges on the Johan Sverdrup project the use of conventional drill and blast methods was investigated but found to represent a too high risk. This was because of the proximity to existing live pipelines in the fjord and no reference to any previous rock removal, using drilling nor blasting at this water depth. Scanmudring was approached by Equinor to perform a feasibility study for the rock removal required at the landfall tunnel exit area outside Mongstad to allow for a safe pull-in of Johan Sverdrup oil pipeline. The feasibility study evaluated a wide range of available tools for subsea rock removing, all tools suitable of being mounted on the existing Scanmudring hydraulic subsea excavator. Based on the analysis of the rock formations outside Mongstad showing a high degree of faulting and fractures, it was expected that rock breaking equipment would be the best solution to remove the desired amount of rock. In addition, the study produced by Scanmudring also recommended the use of drilling- and rock splitting equipment as a back-up solution if use of the rock breaker should prove to be insufficient. Both proposed methods were based on use of Scanmudring hydraulic subsea excavator (Scanmachine#3) mounted in a subsea basket, hanging 15m above seabed from the vessel crane, as the work area could not be reached by the machine when resting on the seabed. Hanging from the crane opened for work at any height above seabed, but it also introduced uncertainties with regards to great strain on equipment and required the vessel to be fully involved in the operation at all time. The rock removal tools were designed and built in less than 6 months, from feasibility to operation, and was successfully used on the Johan Sverdrup Project removing rocks on deep water outside Mongstad. In fact, the cost-effective use of the rock removal tool outside Mongstad revealed that the tool could be used for other seabed intervention tasks on the same project, and Scanmudring was requested by Equinor to remove outcrops at two locations further out the pipe line route in Fensfjorden, on the west coast of Norway. This paper will first present the tools developed for cost-effective deep-water rock removal, and then describe the successful use of the rock removal tools for the Johan Sverdrup project.

TOOL CARRIER AND ROCK REMOVAL TOOLS

Tool carrier: Scanmachine#3 is a 13T subsea excavator and tool-carrier system based on a modified construction excavator benefiting from the long experience and ruggedness of existing land-based construction machines. The heavy duty Remotely Operated Vehicle is set up to be used as a general tracked tool carrier with open interfaces for a broad range of subsea equipment and shore-based construction tools. Scanmachine#3 is the smallest out of four subsea excavators available from Scanmudring. For navigation and monitoring of the machine and work site, a live feedback simulation is part of the system. This enables the operators to keep track of machine movements relative to survey and positioning data fed into the graphical presentation software. The same software (PDS) is also used during planning and simulation of scope of work. Power, control and video to the machine is provided through a single umbilical cable, providing electric power to hydraulic units, water pumps, and in this case also power for the drilling and hydraulic ripper. All equipment in the spread is modular and designed for transportation on standard trucks. The spread includes containers for control, workshops and stores. All supply and interconnect cables are designed for rapid set up on board a support vessel, or other work site.

For work done at Mongstad and Fensfjorden/Holmengraa, the Scanmachine was placed in a customized four point lift subsea basket in contrast to the normal single point lift of the Scanmachine. This solution was chosen to make it possible to get a more stable platform as operation had to be performed hanging in the vessel crane.

Figure 1: Picture showing Scanmachine#3, in this case placed in basket, equipped with the ripper tooth.

Hydraulic ripper: The hydraulic ripper is a demolition tool developed with the latest advances in demolition in mind and is designed to be used on land and in shallow water depth. In cooperation Scanmudring and the manufacturer customized the hydraulic ripper to be able to work in deep waters down to 1000m. The Hydraulic ripper was modified with an adjustable compensator system on the gear box and on the accumulator to be able to resist the environmental pressure.

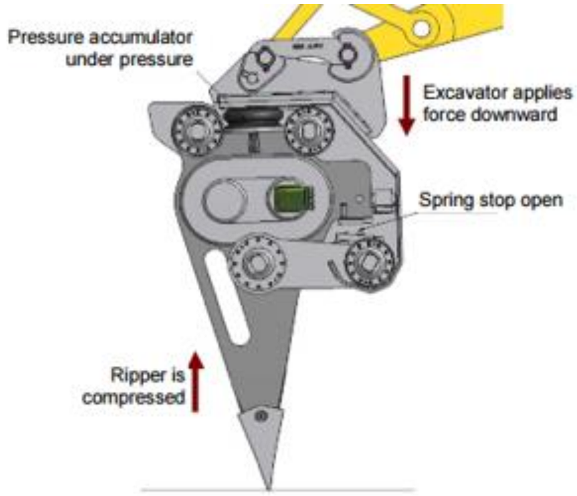

Figure 2: Illustration showing hydraulic ripper used for the project.

The hydraulic ripper was integrated with the Scanmachine#3 control system where all subsea pressure sensors, operation and live 3D view of Scanmachine with hydraulic ripper tool is displayed. This results in an efficient tool with control of functions and angle of attack. Rock breaking with this method is more efficient than a traditional hydraulic rock breaker in rock type with a rock hardness below 100 MPa.

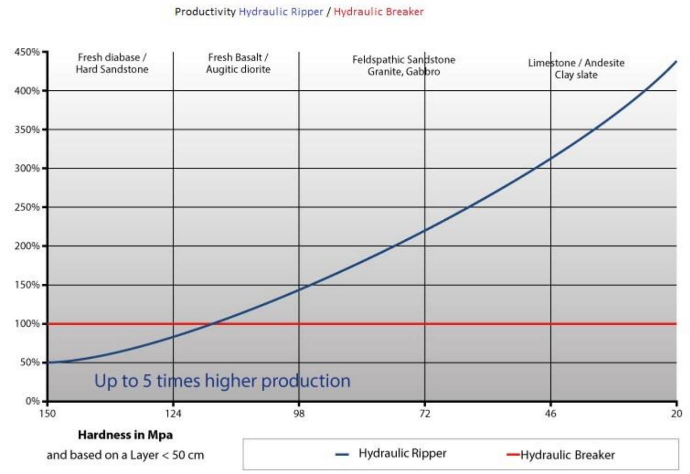

Figure 3: Illustration showing productivity comparison of hydraulic ripper and hydraulic breaker. Chart from supplier of hydraulic ripper.

With rock hardness higher than 75 MPa, the ripper is dependent on fractured rock formation. If the rock formation is solid and doesn't consist of any fractures, drilling and blasting/splitting can be an alternative if the environmental and safety aspects are permitted.

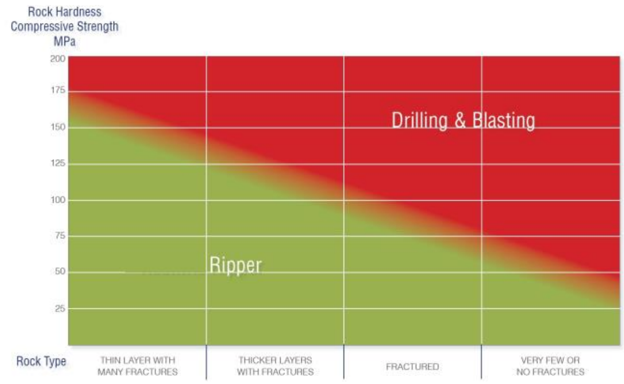

Figure 4: Illustration showing productivity comparison of hydraulic ripper and blasting. Chart from supplier of hydraulic ripper.

Drill rig: The drill rig for the Scanmachine is a custom-made low weight tool designed for subsea use. The drill rig has three main components: drill mast, rotary head and the Water Down the Hole hammer (WDTH Hammer).

Figure 5: Illustration showing graphical display of the drill rig.

All hydraulic functions, and the required high-pressure water supply were controlled and powered from the Scanmachine. Operating functions and feedback were added to the control interface allowing the operator to have full control of the drilling, operating from the control container. The drill mast has three hydraulic functions: tower displacement, drill string feed/weight on bit and tower angle adjustment in two directions. All movement and display of angles are interfaced in the Scanmachine live simulation feedback. This allows the operator to be in control of the borehole angles, without basing angles on visual guess work from video feed. A custom-made drill string guide with a vacuum dust removing system was made to keep the visibility clear and to resist wear and tear. The dust was sucked away, using a small ejector. Ejectors are typical components in Scanmudring common line of work.

Figure 6: Picture showing rotary head and base of drill rig.

Drill string rotation speed and torque is controlled with the rotary head. The rotary head swivel transfers high-pressure water to the water powered hammer. A WDTH hammer introduces several key benefits that makes it perfect for deep subsea use. The main benefits being supply of water and that water, in practical terms, is neutral to ambient pressure. This type of bore hammer provides high drilling performance with state-of-the-art borehole accuracy (Bruce, D.A 2013, Tuomas, G 2004). Use of water, as opposed to mud etc, is also environmentally friendly, making it perfect for use in sensitive areas. The 3" hammer was equipped with a 3.5" drill bit, to accommodate the hydraulic splitters. This bore hole size is also suitable for conventional blasting methods.

Hydraulic splitters: The hydraulic splitter system is a non-vibration rock breaking method. This is a good tool to use on sites where there is a restriction or ban for the use of hydraulic impact hammers or conventional blasting methods, like near to electrical supplies, gas mains, water mains, or other services that can be adversely affected by vibration and fly rock. The rock splitter is a cylinder design with 11 hydraulic pistons that push the rock towards the free face side. The system can be used as a single splitter or with several splitters in parallel.

Figure 7: Picture showing hydraulic splitters.

The operating pressure for the rock splitters is 1200 bar and this is provided and controlled by the Scanmachine. The splitting force of each piston is 19,3 tons and have a max stroke length of 29 mm. The total splitting force with one cylinder is 212 tons. The rock splitting system used on the Scanmachine have a quantity of 4 cylinders resulting in a total splitting force of 848 tons. This system was modified to subsea use with ROV friendly handle bars and quick release on the hydraulic hoses to be able to abandon splitters in case of emergency.

VESSEL, WORK PLATFORM

The work platform in all the three described cases was Edda Flora, a construction vessel operated by Deep Ocean. Edda Flora is designed for subsea Inspection Maintenece and Repair (IMR), and survey operations. The vessel is equipped with Dynamic Positioning (DP), a 50T Active Heave Compensated (AHC) crane, two work class ROVs (Remotely Operated Vehicles) and state of the art survey spread, including multi beam survey and photogrammetry. All features were vital to the operations at Mongstad and Fensfjorden.

Figure 8: Picture showing Edda Flora, IMR and survey vessel.

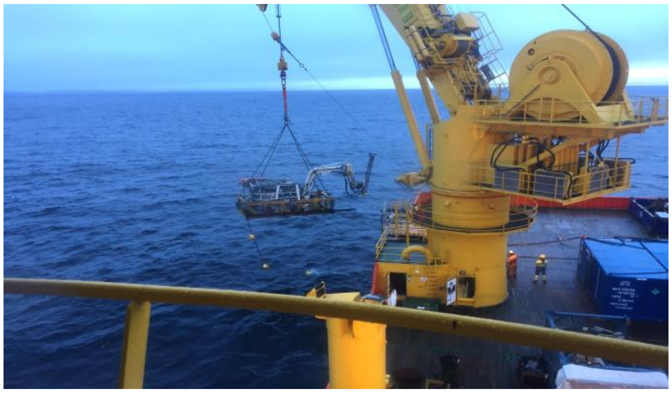

Figure 9: Picture showing deployment of Scanmachine #3 from Edda Flora.

DEEP WATER ROCK REMOVAL AT MONGSTAD

The 800m long landfall tunnel with a diameter of 48” allow the 36” pipeline to be pulled onshore and connected to the receiving facilities. The landfall tunnel exit is at 305 meters water depth, in a steep cliff 15m above seabed. The tunnel has been drilled through hard rock mainly consisting of Anorthosite in exchange with Gabbro.
A detailed survey performed by Deep Ocean after the punch out revealed a rock outcrop a few meters outside the exit point that would prevent a safe pull-in of the pipeline.
Drilling a new landfall tunnel was considered to delay the whole Johan Sverdrup Oil and Gas project, so a subsea rock removal solution had to be investigated.

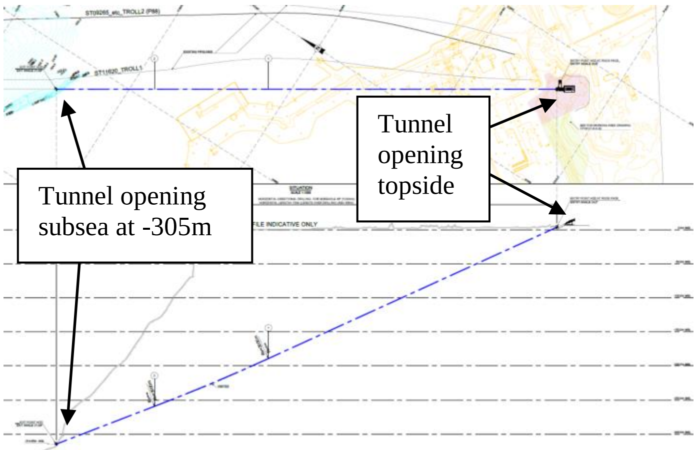

Figure 10: Illustration of Johan Sverdrup Export Pipeline shore landing.

Figure 11: Picture taken from ROV video survey prior to any rock removal.

Figure 12: Picture taken from ROV video as left survey, just prior to pipe pull-in.

Volume calculations based on the initial survey indicated that approximately 6m³ of rock had to be removed, to ensure a safe pull-in of the 36” pipeline. This estimate did not include any rock that had to be removed to access the work area. Video also indicated a high degree of faulting and fractures in the rock face. The surveys were conducted by ROV, set up with double multi beam, photogrammetry and standard cameras.

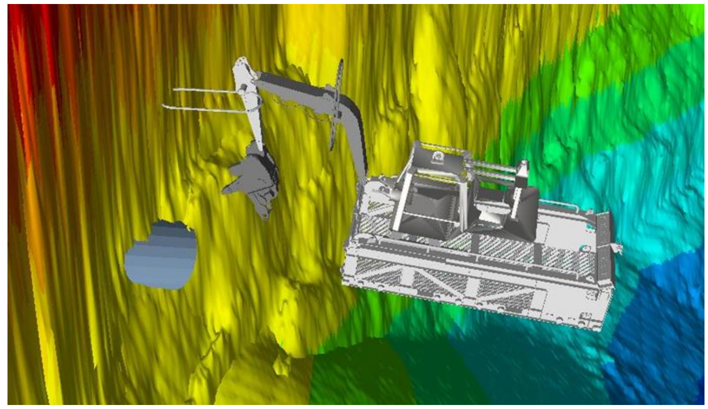
Figure 13: Illustration from Scanmudring Monitoring system, based on rock face as found survey. Scanmachine with rock breaker equipment.

The hydraulic ripper was used in phase 1 for removing rock at Mongstad. The subsea modified hydraulic ripper showed to be effective on the faulted and fractured rock as expected, but the rock formation proved to be more solid than the initial analysis indicated. Still after removing about 25m³ of fracture rock, the intermediate photogrammetry survey revealed that the clearance between the rock and the planned pipeline route was not enough to allow for a safe pull-in of the pipeline.

This called for phase 2 of rock removal, using rock drilling and hydraulically powered rock splitters. After splitting the rock, the loose blocks had to be removed by a ripper tooth. The tools and equipment identified in the feasibility study, was ordered and modified for subsea operation with the Scanmachine tool carrier.

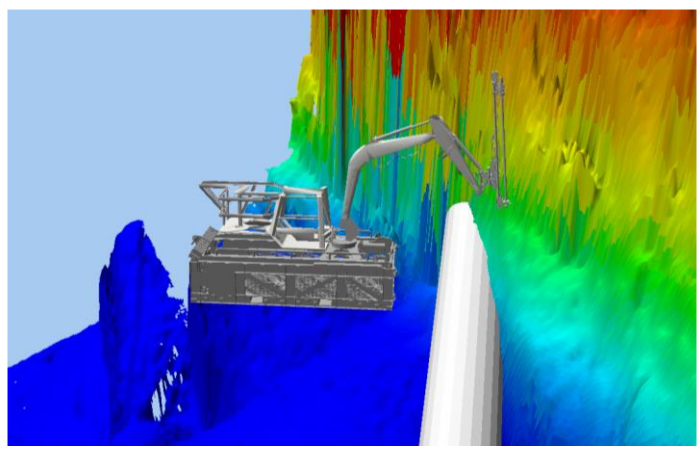
Figure 14: Illustration from Scanmudring Monitoring system, based on survey, post rock breaker operation. Scanmachine with drilling equipment.

The drilling-and rock splitting was also conducted hanging in a subsea basket, from the vessel crane. The strain on the equipment called for several in field modifications and maintenance operations, unlikely to be experienced with the machine resting on firm ground. During this campaign approximately 150 holes were drilled, with depths ranging from 1 to 3 meters. Several of the drilled holes were not used, as loose gravel blocked the holes when retrieving the drill string, preventing the ROV to insert the hydraulic rock splitter. The loose rock after splitting was removed with the ripper tooth. (Tooth shown in Figure 1)
As the work proceeded, intermediate photogrammetry survey data was used as guidance showing clearance between the rock and the planned pipeline pull-in.

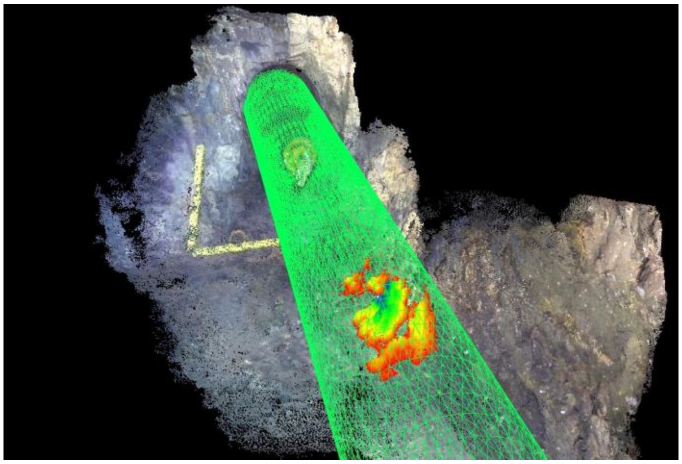

Figure 15: Intermediate Photogrammetry outside the tunnel exit, color codes revealing remaining rock to be removed. The tunnel extension/planned pipeline route is indicated with the green mesh.

Even though the amount of rock that had to be removed became higher than anticipated, the rock removal turned out to be a success and the work was completed in due time for the arrival of the pipeline installation barge and pull-in of the pipeline.

DEEP WATER ROCK REMOVAL WEST OF THE HOLMENGRAA LIGHTHOUSE

During detailed design for the pipeline focus was set on optimization of the seabed intervention, mainly performed by rock installation to prepare the seabed for pipeline installation. With the new rock removal tool package proven to be successful at the landfall, it was decided to investigate if rock removal further out in the fjord could reduce the rock dumping volumes and hereby the cost. If a high point on the seabed could be lowered, the rock berms to support the adjacent free span could be reduced. It was also investigated whether rock removal could make the installation tolerances more robust, by reducing the risk for the pipeline to be damaged by contact with the rock wall during installation. One critical location with a rock outcrop that represented a risk for the pipeline installation was identified. This outcrop was located at 480 meters water depth, at the outskirts of Fensfjorden, west of Holmengraa lighthouse.

A terrain model was made and Scanmudring developed a method statement for removal of the overhanging outcrop, based on the same operational mode with drilling and splitting as used for the landfall location.

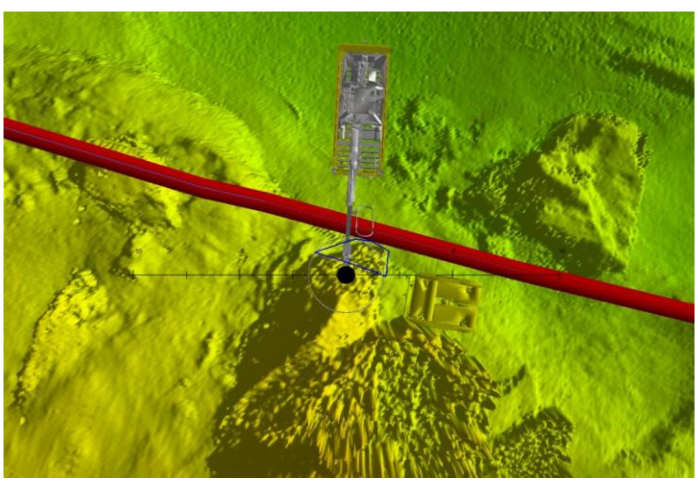

Figure 16: Illustration from Scanmudring Monitoring system, based on survey from the pipe lay route. Planned angle of attack for breaking off the outcrop tip west of Holmengraa lighthouse.

Scanmudring was at the time mobilized on board Edda Flora with the drilling and splitting spread, completing work at the Mongstad tunnel exit.

Based on the available survey, it was anticipated that the outcrop most likely consisted of granite and had an overhang. The rock from the removed outcrop could safely drop down onto the seabed, without representing any risk for nearby pipelines or conflicting with installation of the new pipeline.

A total of 5 holes were drilled, with depth ranging from 2 to 3 meters. The main run with splitters broke off a substantial piece of the outcrop, followed by a second run, re-using the already drilled holes. Loose rock was broken off using the ripper tooth, and the as-left survey indicated that approximately 25m3 of rock were removed. The work at this location was completed within 18.5 hours. The operation was highly successful and proved the capacity of the new developed tooling package for further use.

DEEP WATER ROCK REMOVAL EAST OF THE HOLMENGRAA LIGHTHOUSE

Another outcrop was identified only a few hundred meters east from the previous location at 495m water depth. By lowering this outcrop, substantial reduction to the rock volumes required for pipeline supports could be achieved, and at the same time ease the pipeline installation. This outcrop did not have any overhang, and volume desired to be removed was calculated to be 36m³. No geotechnical data was provided for the rock in this area and the operation was planned based on the experience gained from the first outcrop removal in Fensfjorden.

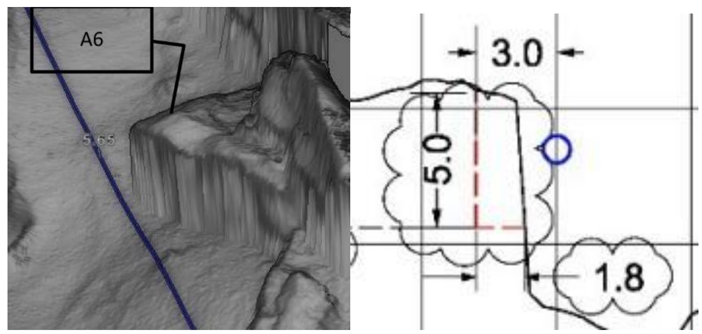

Figure 17: Illustrations from "SOW: For outcrops removal close to Pre-Lay IW12", and 3D graphic from Equinor ST17527-report, describing the outcrop east of Holmengraa lighthouse.

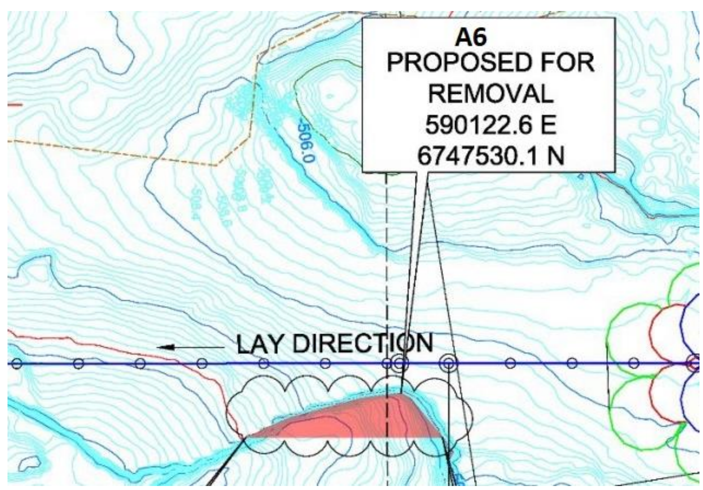

Figure 18: Illustration from "S.o:W for outcrops removal close to Pre-Lay IW12", describing the outcrop east of Holmengraa lighthouse.

Scanmudring was again mobilized on board Edda Flora, with the same spread as for the two previous locations. The work east of Holmengraa lighthouse proved to be more challenging than expected caused by the positioning of the equipment, the geometry of the outcrop, the type of rock and the weather. Substantial amounts of rock had to be removed to

be able to access the 36m3 of rock. The type of rock found at this location turned out to be of phyllite, an elastic rock that is difficult to split with the stroke length available from the rock splitters. A total of 189 holes were drilled, with depth ranging 1 to 3 meters, with the typical hole being 1,5 meters. The hydraulic ripper was also used, in combination with the simpler mechanical ripper tooth. As-left survey indicated a total of 90 m³ was removed at this location
The rock removal operation lasted 41 days, including mobilization, demobilization and 9 days of waiting on weather. The work was performed during winter time, which can be challenging on the coast of Norway. The progress was clearly affected by the movement of the machine, hanging in the crane wire above seabed at 480-490 meters water depth, as the vessel operated in rough sea.

The rock removed at the location east of Holmengraa lighthouse provided improved pipe lay tolerances and reduced the rock volumes required for the pipeline support.

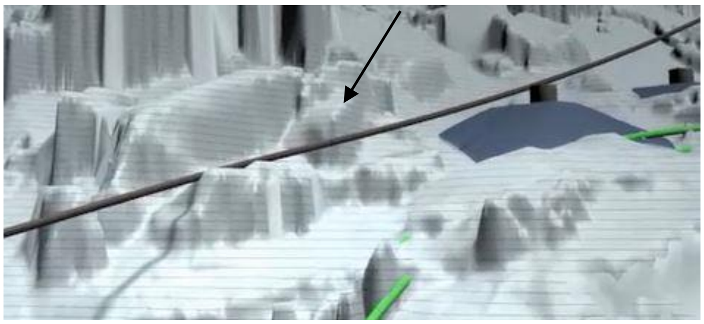

Figure 19: Illustration showing simulation of pipe lay, with terrain based on survey from the pipe lay route. The arrow points out the area of concern, east of Holmengraa lighthouse, at 495meters water depth.

CONCLUSIONS

The developed tools for deep water rock removal was successfully used for the Johan Sverdrup project securing a safe pipeline installation, and the tool package is considered as a tested and proven technology for deep water seabed modification. The rock removal method and equipment developed represent an important environmentally friendly and cost-efficient tool for deep water seabed intervention in areas with challenging bathymetry.

The developed tool package with the drill tower mounted on the Scanmudring hydraulic subsea excavator is considered highly suitable for a wide range of coastal engineering tasks on both shallow and deep water in addition to rock removal as described in this paper. Examples of potential use are deep water rock anchored mooring points, rock mounted pipeline/power cable brackets, rock anchored pipeline counter acts. Other possible extensions in the future: larger/smaller diameter bore holes, deeper holes, automated drilling, sample core drilling, operation at deeper waters.

The fast track development project for Johan Sverdrup also proved that the Subsea hydraulic excavators (Scanmachines) are very flexible and can be modified to fit most hydraulic tools if the tool weights are within the limitations of the excavator. The adaption of known and tested onshore rock drilling and demolition equipment to subsea remote operations proved to be successful. The subsea machines are using standard hydraulic interfaces that opens for potential use of a wide range of standard onshore tools modified to withstand the subsea environment.

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Hydraulic ripper

Teledyne Reson – Rotterdam, Netherlands
PDS, live feedback simulation software

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